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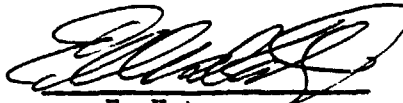
SIMULATED EVA OPERATION
OF A
REMOTE CONNECTOR ASSEMBLY
TEST REPORT

FEBRUARY 1979

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FOREWORD

This Test Report, Simulated EVA Operations of A Remote Connector Assembly is submitted by Rockwell International Corporation, Satellite Systems Division to George C. Marshall Space Flight Center, as required by Contract NAS8-33146, dated August 22, 1978.

This report fulfills the reporting requirements of the Contract.

Where both SI units and customary units (inches) are expressed in this report, the customary units were used for the principal measurements.



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1.0 INTRODUCTION

Rockwell International in consort with the Marshall Space Flight Center has conducted testing to evaluate a connector concept applicable to EVA activities in the construction of Large Space Structures. The application pertains to activities such as cable interconnections between installed modules on a network truss platform. A very limited background exists for the design of electrical connectors to be joined in the space environment, however, the requirement for such operations is evident in future large space construction. As part of its FY78 IR&D Program, the Satellite Systems Division of Rockwell designed and fabricated an experimental connector device for the purpose of testing its design and operational features in simulated operational situations.

The neutral buoyancy simulator at MSFC was used to provide simulation of zero gravity with test personnel wearing EVA suits.

2.0 PURPOSE

The purpose of the test was to evaluate the features of a connector concept with respect to timelines and ease of connection by EVA, in various mating orientations.

Because this testing is very preliminary in the course of technology development, the purpose was not to evaluate the performance of a developed system, but to determine the areas in which development should be directed. Criticism of the connector design and of the test conditions were desired in addition to time measurements to obtain qualitative as well as quantitative data.

The specific objective then, was to generate data which would be useful in defining the design requirements for future development and testing, and the guidelines for applications to future large space structures.



3.0 SUMMARY

The connector tests were conducted by three (3) EVA astronaut test subjects. Each of four (4) test conditions -- Baseline, Off Angle, Overhead, and with Visual Obstruction -- were run three (3) times by each of the test subjects.

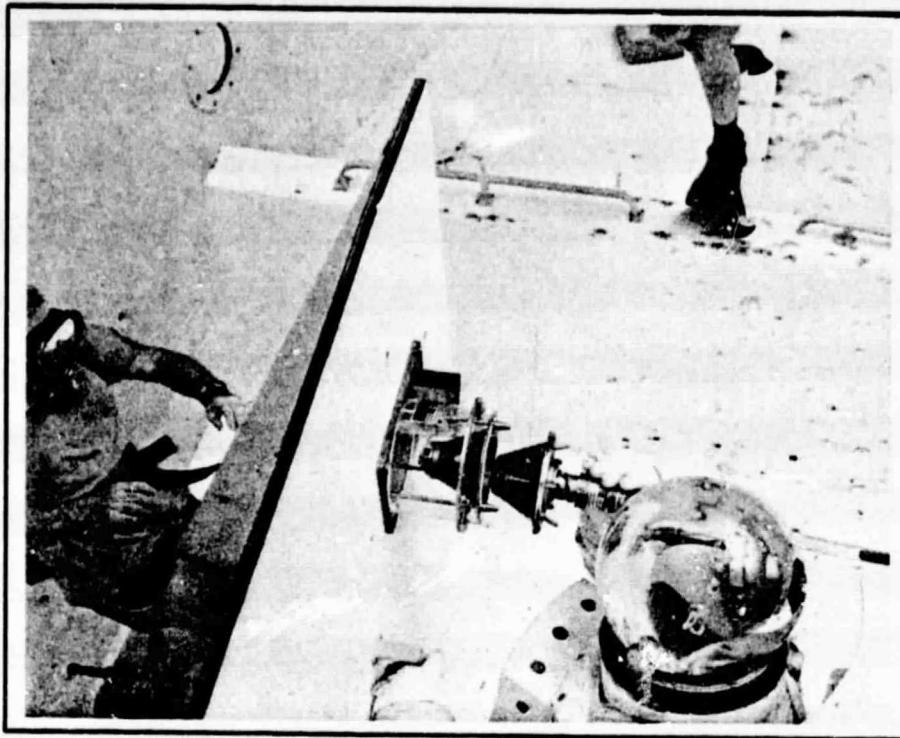
Time data were taken on each test run. Visual and voice communications with the subjects were recorded in addition to post-test debriefing comments.

A typical baseline test insertion is illustrated by the photos, Figure 1.

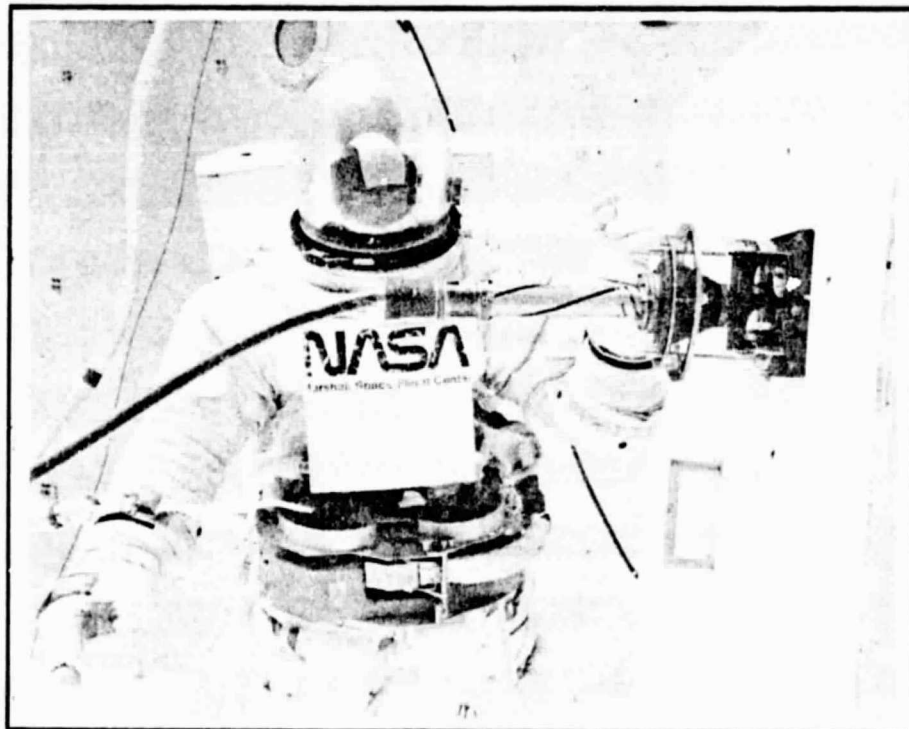
The tests successfully demonstrated that EVA personnel can perform connection tasks in relatively short times (generally under 1 minute), and that the connector configuration was a reasonable design base for such tasks. The tests also demonstrated the difference in relative work loads imposed by the four (4) test conditions. The test data were, however, too limited to identify any learning characteristics or trends.

The in-situ communications and post-test comments indicated that the connector was generally acceptable but requires improvement to its manual interface features. Comments also noted that the installations and locations of manual/facility interfaces - handholds and foot restraints are very critical to the task effort and time, and must be carefully integrated into the overall design of the connection system.

Improvements in hardware and facility designs suggested by these tests could potentially result in average connection times of 30 seconds during EVA operations.



Overhead
View



Side View

Figure 1. Test Photos

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4.0 TEST DESCRIPTION

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4.1 TEST SPECIMEN

The test specimen, Figure 2, consisted of the two mating halves of a connector which were manually joined by the EVA test subject. The connector handhold was designed to be held by either an EVA test subject or a remote manipulator end effector. A simulated electrical cable extended from the rear of the probe a distance of approximately 30 feet.

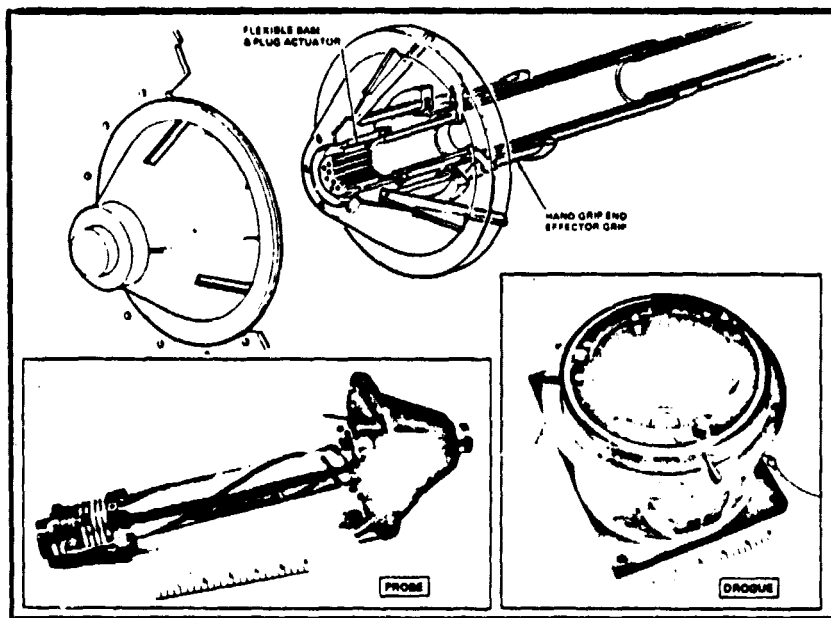


Figure 2. Connector Hardware

The connector features are (1) a latching cone and drogue interface which provides a precision location and orientation for subsequent electrical plug/pin insertion, (2) an angular compliance of the cone to promote the ease of initial attachment, and (3) a plug insertion mechanism which provides a mechanical advantage and an appropriate manual motion for the connection operations. Pushing on the handhold advances the connector to make a latching attachment of the cone and drogue. Retraction of the handhold extends the electrical plug into the socket.

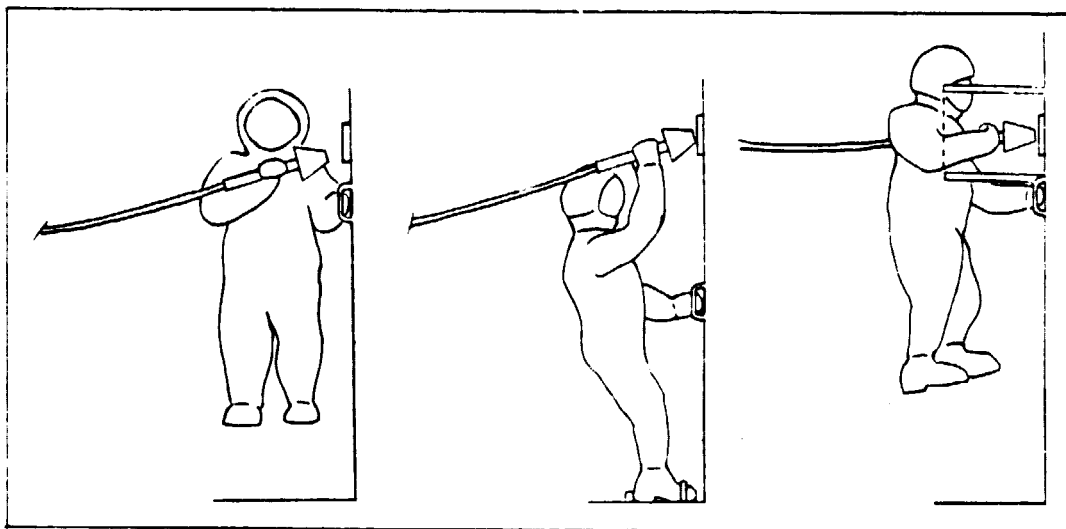


To signal the successful completion of each test run, the pins in both halves of the electrical plug were wired in series such that when all 21 pins were engaged, a battery powered test light on the drogue was energized.

4.2 TEST CONDITIONS

For all tests, the test subject, attired in a pressure suit, positioned himself initially at some distance from the task board with the test connector in hand. The task consisted of approaching the task board, using the handrail, grasping the appropriate handhold and/or foot restraint for body positioning, and making the connection. Timing of the task was recorded in three increments: (a) from the start of approach until the subject first contacted with the task board; (b) from the end of time (a) until the subject first established his body in position to make the connection; (c) from the end of time (b) until the connection was made and the test-light indicated that all electrical pins were engaged.

Four (4) different test conditions were employed, see Figure 3.



Baseline & Off Angle
Conditions 1 & 2

Overhead
Condition 3

Obstruction
Condition 4

Figure 3. Body Positions Corresponding to Four Test Conditions



o Condition 1, Baseline

Drogue at shoulder height with the connector cable slack. Cable is tied down in-line.
Test subject approaches task board with plug in hand.
Subject grasps handhold and performs connection task.

o Condition 2, Baseline Off-Angle

Drogue at shoulder height but with the connector cable tied down taut at an offset angle.
Subject performs connection task as in Condition 1.

o Condition 3, Overhead

Drogue at maximum overhead reach with the test subject using foot restraints.
Cable is tied down in line, slack.
Test subject approaches task board with plug in hand.
Subject grasps far handhold, engages foot restraints and performs connection task.

o Condition 4, Obstruction

Drogue at shoulder height inside an obstruction which would prevent visual observation of the receptacle during the final mating operation.
Cable is tied down in line, slack.
Test subject approaches task board with plug in hand.
Subject grasps near handhold, observes drogue location and orientation inside the obstruction, and then performs connection task without visual access.

Each of these conditions were run three (3) times by three (3) different test subjects.

4.3 TEST FACILITY

The tests were performed in the neutral buoyancy simulator (NBS) at MSFC, Reference 1, at a depth of approximately 30 feet. Figure 4 gives a general perspective of the facility and test setup. An Orbiter Cargo Bay simulator was used to mount the test apparatus which consisted of a handrail for test subject translation and a task board, mounted vertically with the receptacle, handholds and foot restraints; see Figure 5.

The test subjects were accompanied by two (2) safety divers. The setup changes and equipment handling were performed by several utility divers. The control station - test director, et.al, monitored all test activities by CCTV and voice communication.

4.4 INSTRUMENTATION

All test times were recorded on timers in the control station from CCTV observations and indications from the test subjects of activity completions. Continuous monitoring of all test activity was made on video/audio tape from selected TV camera locations and voice communications. Four (4) cameras were in operation. 16MM motion pictures were taken of selected sections of the test that might be representative of each different activity. Still photos were taken of selected activities. All movies and stills were taken underwater by divers.

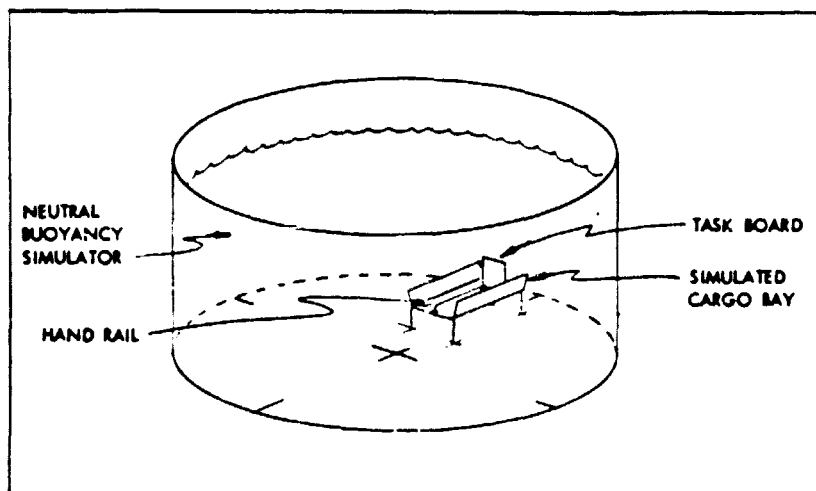
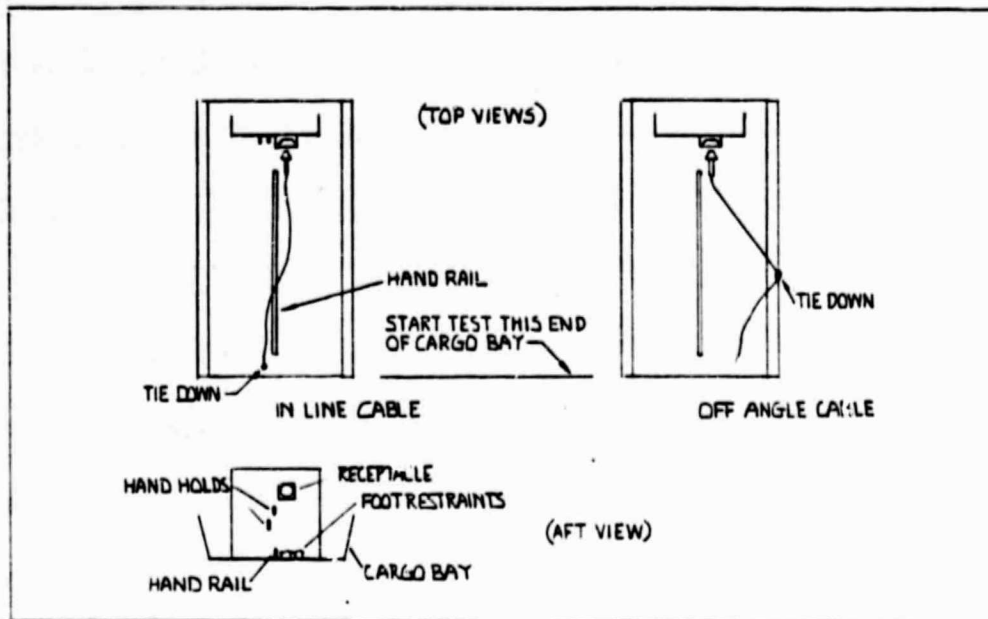
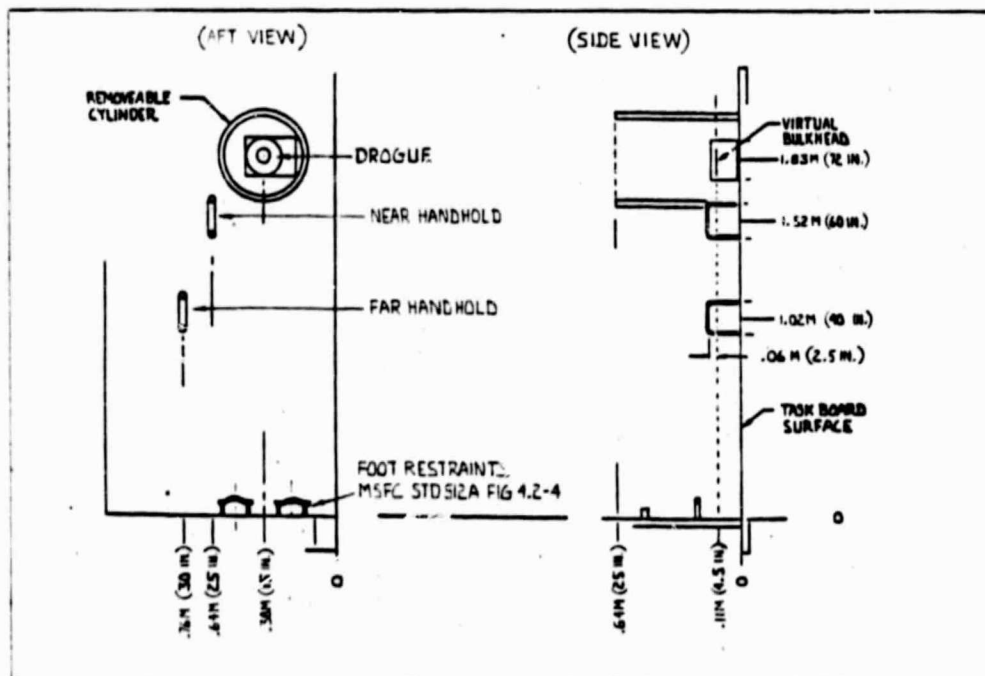


Figure 4. Facility & Test Setup



(a) Cargo Bay Arrangement



(b) Detail of Task Area

Figure 5. Test Setup



5.0 CONDUCT OF TESTS

The following test procedures were prepared and test subjects were briefed on the task sequences before testing. Test subjects were asked to depart from the planned operations if the sequence became too difficult.

Task 1 - Baseline Test

- 1.1 Start with Plug in Hand
 - 1.2 Approach Task Board
 - 1.3 Grasp near Handhold
 - Commence Time
 - 1.4 Connect Test Connector
 - 1.4.1 Locate
 - 1.4.2 Attach/Latch
 - 1.4.3 Insert
 - Lamp Energizes, Note Time
 - 1.5 Retract Connector
 - 1.6 Unlatch
 - 1.7 Detach
 - 1.8 Retreat
 - 1.9 Restore Unlatching Ring
- Repeat 1.1 thru 1.9 for a total of 3 trials.

Task 2 - Baseline Off-Angle

- 1.1 Start with Plug in Hand
 - 1.2 Approach Task Board
 - 1.3 Grasp Near Handhold
 - Commence Time
 - 1.4 Connect Test Connector
 - 1.4.1 Locate
 - 1.4.2 Attach/Latch
 - 1.4.3 Insert
 - Lamp Energizes, Note Time
 - 1.5 Retract Connector
 - 1.6 Unlatch
 - 1.7 Detach
 - 1.8 Retreat
 - 1.9 Restore Unlatching Ring
- Repeat 1.1 thru 1.9 for a total of 3 trials.



Task 3 - Overhead Test

- 1.1 Start with Plug in Hand
 - 1.2 Approach Task Board
 - 1.3 Grasp Far Handhold
 -- Commence Time
 - 1.4 Engage Foot Restraints
 - 1.5 Connect Test Connector
 - 1.5.1 Locate
 - 1.5.2 Attach/Latch
 - 1.5.3 Insert
 -- Lamp Energizes, Note Time
 - 1.6 Retract Connector
 - 1.7 Unlatch
 - 1.8 Detach
 - 1.9 Retreat
 - 2.0 Restore Unlatching Ring
- Repeat 1.1 thru 2.0 for a total of 3 trials.

Task 4 - Obstruction Test

- 1.1 Start with Plug in Hand
 - 1.2 Approach Task Board
 - 1.3 Grasp Near Handhold
 -- Commence Time
 - 1.4 Connect Test Connector
 - 1.4.1 Locate
 - 1.4.2 Attach/Latch
 - 1.4.3 Insert
 -- Lamp Energizes, Note Time
 - 1.5 Retract Connector
 - 1.6 Unlatch
 - 1.7 Detach
 - 1.8 Retreat
 - 1.9 Restore Unlatching Ring
- Repeat 1.1 thru 1.4 for a total of 3 trials.

Repeat Task 1 thru Task 4 for a total of 3 test subjects.

All testing was conducted on Thursday, 24 August 1978. The first two (2) test subjects were run in the morning and the third in the afternoon.

The first test subject was Richard Heckman, 5'10", experienced in underwater suited activity; test conductor: Larry Fleming, MSFC. The second test subject was Scott Croomes, 6'0", somewhat less experienced in underwater suited activity; test conductor: Alan Le Fever, Rockwell International. The third test subject was Craig Sumner, 6'2", left handed, least experienced in underwater activity (had not previously used foot restraints); test conductor: Alan Le Fever, Rockwell International.



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Movies and photo stills were taken by photographic divers in the MBF tank. Video tape coverage, all other test data, and direction and control were carried out in the MBF control station using CCTV and voice communication with the test subjects. The test director for all tests was Charles Cooper, MSFC.



6.0 TEST RESULTS

The test data recorded during the runs were:

1. Time increment "a," in seconds, for test subjects to traverse the length of the cargo bay, with connector in hand, and make contact with the task board. This time was quite uniform between subjects and conditions and has minor significance to the subject test objectives.
2. Time increment "b," in seconds, after time A, for test subjects to position themselves to initiate the connector insertion. This time was significantly different for the different test conditions.
3. Time increment "c," in seconds, after time B, for test subjects to make the connection and verify continuity. This time varied with test conditions and also between morning and afternoon runs, presumably because of readjustment of the connector.
4. CCTV observations of test difficulties.
5. Voice comments of test subjects during test.
6. Post-test debriefing of test subjects.

6.1 TEST TIME DATA

Test time recorded during the entire test cycle are shown in Table 1, except that the following noted times are not considered valid:

- (a) Test times on trials #2 and #3 were lost because of recording difficulties.
- (b) During Condition C tests, subject A dropped the connector probe and was unable to make a rapid retrieval. The trial was aborted after a time increment, "c," of 43 seconds.
- (c) During Condition D tests, subject B was unable to produce a lamp indication of electrical continuity after several attempts to retract the probe handhold. The trial was aborted after a time increment, "c," in trial 1, of 382 seconds and in trial 3, of 260 seconds.



Table 1. All Test Times

RECORDED TIME, SECONDS												
TIME INCREMENT	CONDITION 1 BASELINE			CONDITION 2 OFF ANGLE			CONDITION 3 OVERHEAD			CONDITION 4 OBSTRUCTION		
	A	B	C	A	B	C	A	B	C	A	B	C
TRIAL NO. 1 SUBJECT A	25	14	62	19	5	7	23	23	77	23	25	125
	(a)	(a)	(a)	18	6	9	22	36	(b)	25	24	29
	(a)	(a)	(a)	21	6	125	20	26	66	27	45	15
TRIAL NO. 1 SUBJECT B	20	7	12	26	9	4	24	140	42	15	21	252
	32	6	210	19	6	82	24	33	16	25	24	137
	28	7	6	24	7	13	20	82	14	23	26	(c)
TRIAL NO. 1 SUBJECT C	29	12	48	22	15	27	26	177	14	33	14	(c)
	23	9	28	30	9	29	28	188	11	28	22	65
	29	9	14	26	10	10	34	53	17	20	16	(c)



7.0 DISCUSSION

7.1 TEST TIMES

Test times from Table 1 are separately plotted in Figures 6 and 7 to permit interpretation of the results.

Figure 6 graphically illustrates the time distribution of the test data. The ordinate shows the number of samples falling within 6-second intervals and the abscissa shows the times for the samples represented.

It is noted that the body positioning time increment, "b," generally accounts for a fraction of a minute for the shoulder level connections (Conditions 1 and 2), whereas the overhead connection (Condition 3) requires longer intervals due to the activity of engaging foot restraints.

With respect to the time increment, "c," for making the connection, the data indicate that less than one minute is generally required - except where a "blind" (i.e., obstructed) connection (Condition 4) must be made.

Overall, the time trends showed that less than 1-1/2 minutes was sufficient to accomplish the connector mating task - including body positioning and connector joining. The trends also showed the importance of locating the connector and associated body restraints (hand and foot) to provide eye-level visibility and shoulder height action for direct rapid execution of the joining procedure.

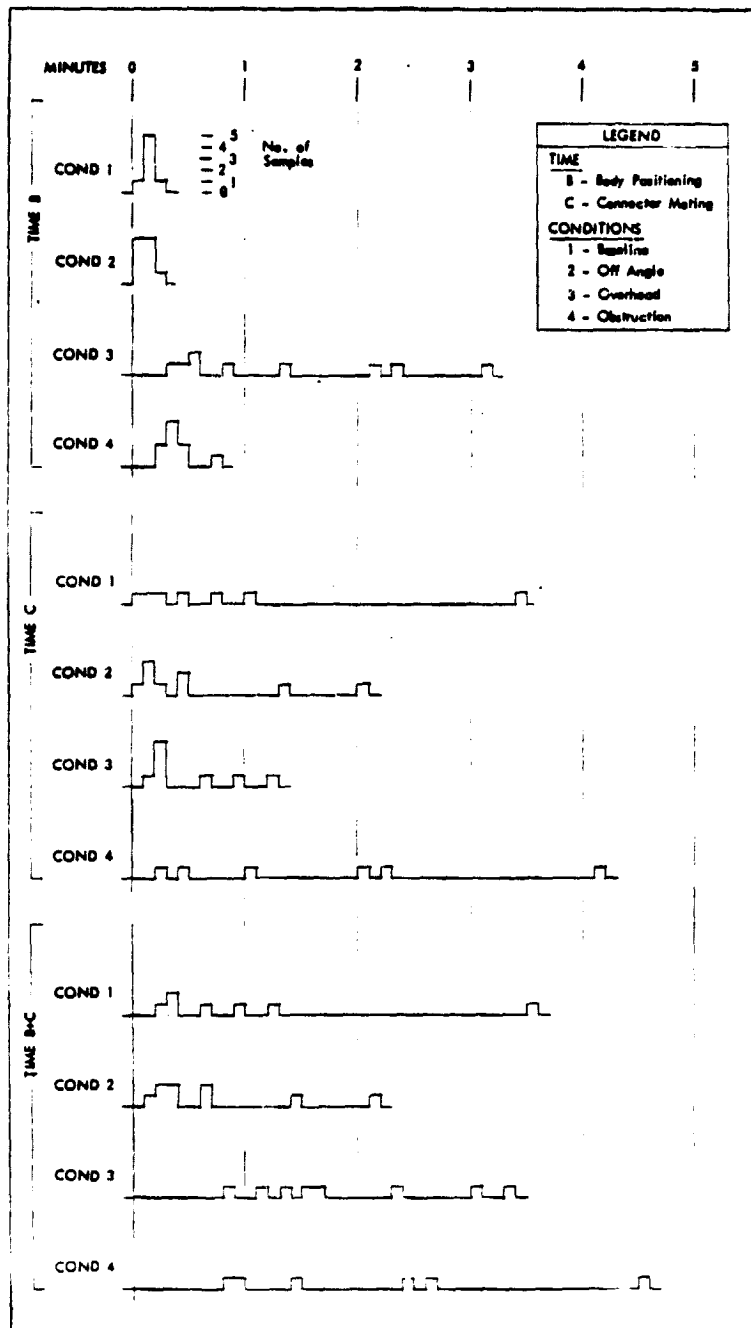


Figure 6. Time Distribution of Test Data



Figure 7 illustrates the sequential distribution of the test data. The ordinates are the times in seconds for each activity by each of the three (3) test subjects, on a logarithmic scale. The average activity time for all subjects and all three (3) trials is shown in the lower chart.

The average activity times and standard deviations,

$$s = \sqrt{\frac{\sum_{i=1}^N (x_i - \bar{x})^2}{N-1}}$$

for the lower chart are also listed in Table 2.

The test plan proposed test Conditions 1, 2, 3 and 4 in what was considered to be an increasing order of difficulty. Test Condition 2, employing a taut off-angle cable, however, proved to be no more difficult than the baseline test Condition 1. Coaxial orientation of cables and connectors in space structures may not be a necessary constraint.

It is noted that nowhere in time increment, "b," and only three (3) places in time increment, "c," is there an indication of a learning trend, as evidenced by a sequential reduction of trial test times. The statistical samples are evidently too few to indicate the minimum operational times that might be achieved with sufficient practice. The average time plots do show a distinctive increase in the time increment, "b," required to position the body in foot restraints, and in time increment, "c," to effect the "blind" connection, as were presupposed. However, the high percent deviation in Table 2 indicate for the foot restraint and "blind" connection, as in several other areas, a lack of uniform repeatability which might be caused by random difficulties.

Table 2. Statistical Data

	Time Increment B				Time Increment C				Time Increment B+C			
Test Condition	1	2	3	4	1	2	3	4	1	2	3	4
Average Time	9.1	8.1	84.2	24.1	54.3	34.0	32.1	103.8	63.4	42.1	122.4	130.7
Standard Deviation	2.9	3.1	66.7	8.8	71.6	41.7	26.3	87.8	71.1	41.1	59.0	83.1
% Std Deviation	31.8	38.2	79.2	35.1	131.9	122.7	82.0	84.5	112.0	97.5	48.2	63.6

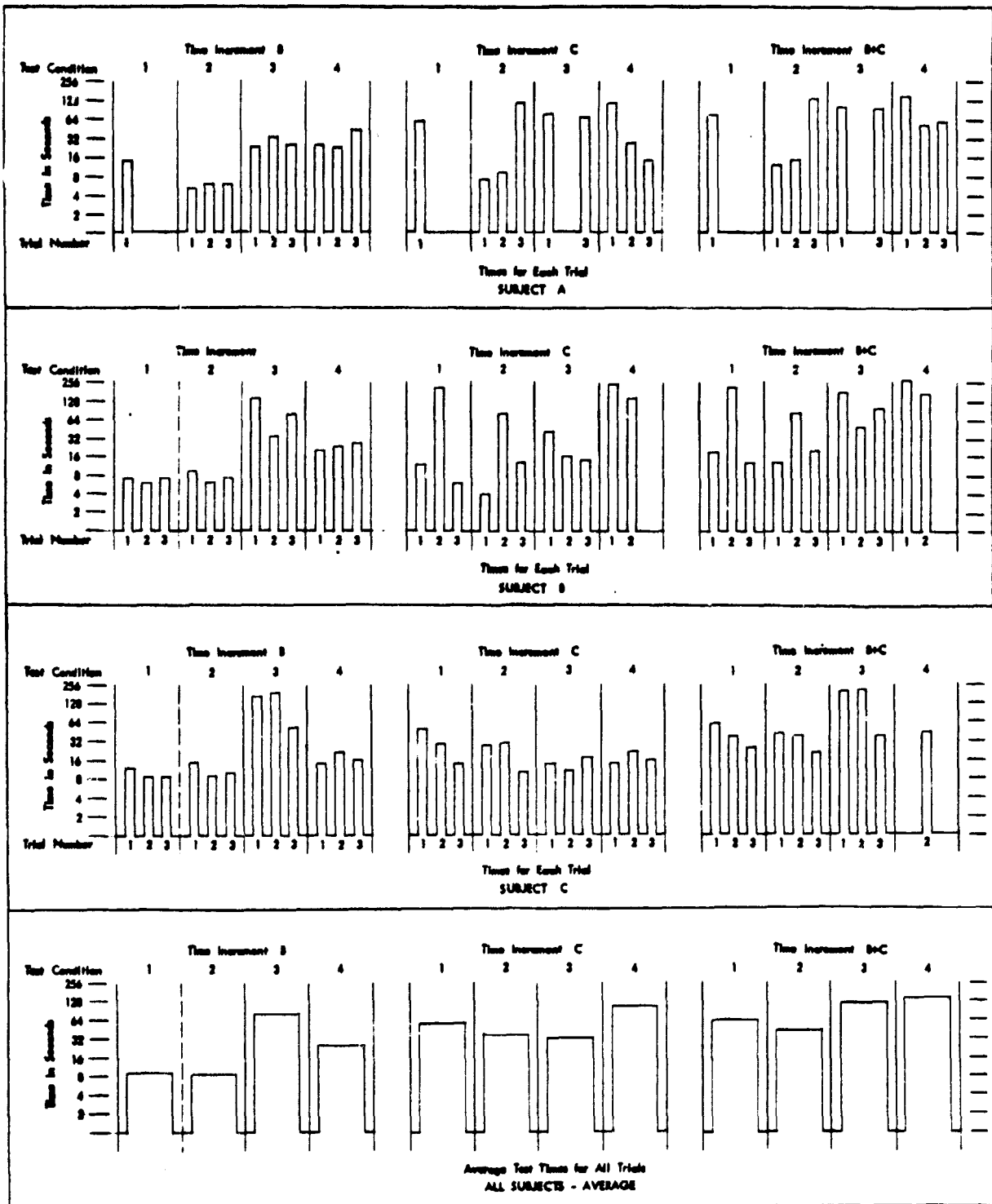


Figure 7. Sequential Distribution of Test Data



7.2 OBSERVATIONS AND VOICE COMMENTS

During the morning testing, it was observed once with Subject A (125 seconds) and once with Subject B (82 seconds) that the connector required two (2) or three (3) pulls on the handhold to produce the lamp indication of continuity. The task times were increased only a few seconds, however, and the recorded data were considered valid. During the break after the second subject tests, the probe was found to have a slight "hang up" in the insertion mechanism. This discrepancy was thought to have resulted from previous hard usage of the probe by the RMS at Johnson Space Center. The probe was realigned and no additional problems were noted until the last trials of the third subject.

It was noted from observation that wrist rotation of the connector in several instances appeared to be difficult for the test subject. Significant rotations were made only by leaving the handholds and using both hands for turning.

Handling Difficulties

Once during the first subject's activity, the connector was dropped and recovery was rather difficult. This trial was aborted. It had been impossible to trim the connector to neutral buoyancy and the descent rate was inconstant with zero g conditions.

Once during the second subject's activity, the connector was dropped but recovered quickly and the trial completed (137 seconds). The second subject had noted during Condition 1 that the connector buoyancy was too negative.

The third subject indicated early in the tests that rotational alignment of the connector was not very easy to do at the final location and needs to be done before the run is started. He also commented that a tether to the connector would be preferable to hand-held transport.

Facility Aids

All three (3) subjects had difficulty using the foot restraints. The first two (2) subjects performed one or more of the overhead (Condition 3) insertions with one or both feet out of the restraints during time C. The overhead height was apparently too great. The third subject (tallest) could maintain foot restraint during time C, but never having used them before, took considerable time in positioning himself in time B. He noted at one point that while holding the connector in one hand, the remaining hand was not sufficient - that two handholds were needed to make the foot engagements.



All three (3) subjects had difficulties with the position of the handholds as being too far removed from the receptacle position, especially for the obstruction (Condition 4) insertions. The first two (2) subjects used the obstruction cylinder as a handhold.

During the break after the second subject's test, a handhold was added to the obstruction cylinder on the left side. After the first trial of the third subject, the cylinder was rotated to place the handhold on the right side (subject was left handed). An immediate reduction in time C was noted for the second trial.

7.3 SUBJECT DEBRIEFING

Following the conclusion of testing, all three (3) subjects were interviewed for comments on the test activity. Comments were made on the facilities and the connector set.

Facilities

One subject stated that transportation along the handrail was difficult while carrying the weighty connector. Another that a tether to the connector would be desirable. These comments are obviously interrelated.

All three (3) subjects commented on and agreed that the handhold placements were too far removed from the action. It was generally agreed that a circular handrail close around the receptacle would have been ideal for all four (4) conditions. The handhold position was the major contribution to difficulties.

Connector Set

Favorable comments on the connector design were:

The flexible feature of the connector cone was helpful, and the push-in, pull-out actuation was good.

The initial rigid latching feature of the probe to drogue was very helpful in relieving the subjects of the stress of transportation.

Unfavorable comments on the connector design were:

The grasping collar of the probe was slightly too large, should have had a flange to pull against and was required to be pulled back too far.

The connector cone need not have been quite so large.

The grasping collar of the probe had an excessive rotational compliance. (This compliance was due in large to the prior hard usage of the connector and was not an initial design feature.)



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A squeeze T-handle, ratched or twist-grip actuation would be preferable to the push-pull feature. (This is in contrast to the favorable comment on the same feature.)



8.0 CONCLUSIONS & RECOMMENDATIONS

The objectives of the test program were met. The task evaluation, activity times and difficulties were demonstrated and recorded, and the design features of the connector pertaining to EVA operation were evaluated.

The tests were successful in demonstrating that a remote connection can be made successfully by EVA in times generally less than one minute; that with proper development of facilities and connector features, the activity might be targeted at something less than 30 seconds.

Although the different conditions relative to the subject's body placements affected the task times, the lack of handholds adjacent to the receptacle proved to be a major facility drawback.

The constraints on the subject's body position and dexterity by placement of handholds and foot restraints greatly affects his ability to make a direct and rapid connection. The facility design and layout of the receptacle portion should be made as non-restrictive as possible of the subject's body position, and should provide handholds immediately adjacent to the receptacle.

The manual dexterity of a suited astronaut is quite limited by the bulk of his pressure suit in all body activities. The design of a connection device should minimize the extent and difficulty of making continuous or discrete manipulations. The grasping interface for transportation and operation should be driven toward standard handhold dimensions (transportation tethers should be considered).

As early in the operation as possible, the connection should be physically latched - as with the cone/drogue - to relieve the astronaut from having to maintain, or hold, the device in place. This latching should be as flexible as possible with respect to orientation, especially regarding wrist rotations. All operations should be minimized as to forces and displacements.



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9.0 DISPOSITION

The connector set, probe and drogue, have been returned to Rockwell International, Downey, California.

10.0 REFERENCES

1. MSFC Contract NAS8-33146 (August 1978), "Test Evaluation of Contractor Furnished Electrical Connector Assembly"